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Marsh accretion and sediment accumulation in a managed tidal wetland complex of Delaware Bay

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ABSTRACT

Wetland impoundments are created to provide ecological benefits such as water quality improvement, mosquito control, and migratory bird habitat. Prime Hook National Wildlife Refuge, located on the southwestern shore of the Delaware Bay, is composed of four interconnected wetland management units. Tidal inflow from Delaware Bay to Units I and IV occurs naturally, whereas flow to Units II and III has been restricted by tidal gates since the mid-1980s. To assess the accretionary status of Refuge marshes and inform an ongoing restoration, we investigated soil physical properties and developed ^{137}Cs and ^{210}Pb radiochronologies for cores collected at twelve sites. Results indicate that marsh accretion is driven by a combination of mineral sediment and organic matter accumulation, the relative proportions of which vary among and within the wetland units. Accretion rates (0.11–0.54 cm/y) were found to be significantly correlated with organic matter accumulation but not with mineral sediment accumulation. These relationships demonstrate that biotic contributions to marsh accretion, such as belowground biomass productivity, must be considered in marsh restoration strategies, in addition to the supply of mineral sediment. At eight of the sites, the contribution of mineral sediment to the total volume of the soils has decreased significantly since the early 1900s, predating the impoundment works, perhaps in association with closure of two tidal inlets by natural processes. By comparison, changes in organic soil volume were relatively small over the same time span. At seven of the sites the marsh is accreting at, to just below, the rate of local relative sea-level rise (0.34±0.03 cm/y) with potential for submergence on the long term. Additional research at the Refuge is needed to better align measurements of marsh accretion, relative sea-level from tide gauges, and wetland elevation change.

1. Introduction

Impounded marshes are coastal or estuarine wetlands in which the natural tidal flow regime has been modified or altogether removed. While effective at modifying flow conditions to achieve a particular goal, impounding a marsh can have negative effects including lowered water tables, ground subsidence, changes in soil salinity, among others (Sturdevant et al., 2002). Moreover, impounded marshes with restricted tides may not have the capacity to accrete at a rate sufficient to maintain an optimal elevation for plant growth. Interest in the ecological consequences of marsh impoundments has included effects on soil chemistry, biomass, and nutrient fluxes, plant and microbial community changes (Boumans and Day, 1994; Montague et al., 1987; Portnoy and Giblin, 1997; Stocks and Grassle, 2003; Sturdevant et al., 2002).

Natural, fully established salt marshes accrete vertically at a rate that approximates the local rate of relative sea-level rise (RSLR) by accumulating organic matter, primarily from plant production, and inorganic (mineral) sediment from tidal deposition. Organic matter preserved in salt marsh soils is derived mostly from belowground production of biomass chiefly in the form of roots and rhizomes. Mineral sediment in marsh soils is sourced from erosional scour of waterway channels and intertidal flats, and in some systems is imported from fluvial sources. In general, vegetative growth and biomass accumulation set the minimum rate of marsh accretion, whereas sediment mass accumulation determines the upper limit. The relative importance of organic and mineral mass accumulation can be determined through studies of soil properties combined with radiochronology (e.g., Nyman et al., 1993; Turner et al., 2000).

The relative contributions of organic matter and mineral sediment to measured accretion rates has been investigated through short-term plot experiments (e.g., Cahoon and Turner, 1989; Calvo-Cubero et al., 2013; Reed et al., 1997), and by regression analysis of radiometrically determined mass accumulation rates (Bricker-

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Urso et al., 1989; Chmura and Hung, 2004; Neubauer, 2008; Nyman et al., 1993; Turner et al., 2000). The following generalizations of salt marsh accretion can be made from the collective findings of these studies: (1) marsh accretion is dependent on both organic matter accumulation than mineral sediment accumulation, but more so dependent on organic matter accumulation in some marshes; (2) variations in organic matter accumulation explains more of the variation in accretion rates and do variations in mineral sediment accumulation in some marshes; (3) and mineral and organic mass accumulation are related through time-dependent feedbacks between physical and biotic factors that moderate plant growth. As an example of the third observation, as a youthful marsh develops from a mudflat and builds elevation within the tidal frame, it tends to trap a decreasing amount of mineral sediment due a reduction in hydroperiod (Allen, 2000). With increasing maturity, belowground organic matter production and accumulation increases thereby increasing soil volume and the rate of accretion (Morris et al., 2002).

In impounded marshes, accretionary deficits are often related to deficient mineral or organic mass accumulation, ultimately as a consequence of altered tidal hydrology and attendant changes in nutrient and sediment supply. Most of the published work on accretion in impounded marshes centers on U.S. Gulf Coast systems, particularly within Louisiana (Cahoon and Groat, 1990; Cahoon and Turner, 1989; Cahoon, 1994; Knaus and Van Gent, 1989; Reed et al., 1997). Comparatively less work has been conducted on the Atlantic and Pacific coasts (e.g., Anisfeld et al., 1999; Sturdevant et al., 2002). Boumans and Day (1994), using sediment traps over two- to four-week intervals, found lower mineral sediment accumulation rates in impounded marshes compared to tidal marshes in Louisiana National Wildlife Refuges (NWR). Similarly, Reed et al. (1997) observed that impoundments in the Mississippi Delta were deficient in mineral sediment when compared to natural reference marshes. Bryant and Chabreck (1998) measured long-term accretion using ^{137}Cs geochronology in NWR impoundments in southwestern Louisiana, finding lower accretion rates in impounded marshes compared to natural tidal marshes. In Long Island Sound, Anisfeld et al. (1999) compared impounded, restored, and reference marshes, finding similar organic and mineral accumulation rates among the three types of marshes, but significantly higher accretion rates in the restored marsh due to the higher porosity soils. A common takeaway of these studies is that the relative contribution of organic solids, mineral solids, and pore volume is highly variable among tidal marshes, and that assessments of marsh accretionary status must be made at the local scale and in consideration of biotic and physical processes of soil formation.

Experience has shown that tidal restoration can lead to rapid organic matter and mineral sediment accumulation, accretion, and elevation increase as the marsh responds to a new tidal frame. The general progression for an initially submerged, unvegetated system is as follows: mineral sedimentation, increasing the bed elevation to approximately mean tide level; colonization of intertidal flats by vegetation; sediment trapping by the marsh canopy; belowground organic matter production and accumulation; and vertical accretion with increased soil volume. Belowground biomass formation can be crucial in the density and accretion rates of created *Spartina alterniflora* marshes (Craft et al., 2002). At former hay farm sites in Delaware Bay, Hinkle and Mitsch (2005) attributed the success of the restoration to the small size of the sites, the proximity of seed sources, and reestablishment of tidal hydrology conducive for vegetative growth. For restored wetlands in San Francisco Bay, Williams and Orr (2002) observed that three physical factors can independently or collectively retard or even prevent vertical accretion and lateral expansion of new marsh: (1) restricted tidal exchange; (2) limited sediment supply; and (3) locally generated wind waves, which by reducing sediment deposition on flats and contributing marsh edge erosion limit expansion of pioneer marsh. Despite the initial success of many restorations, long-term monitoring has shown that years to decades must pass before restored wetlands provide the same level of ecosystem services (such as carbon sequestration) as natural wetlands (Craft et al., 2003).

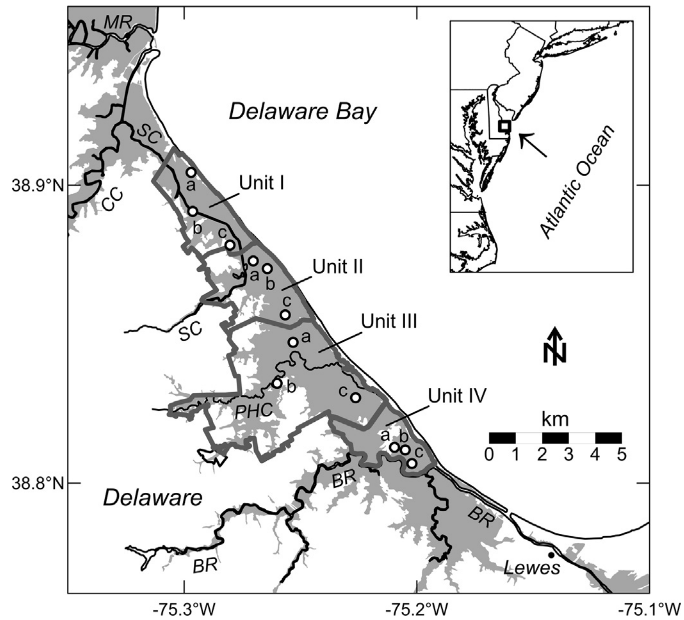

Fig. 1. Location map for Prime Hook National Wildlife Refuge showing the boundaries of management Units I–IV and locations of marsh cores collected for this study. SC = Slaughter Creek, PHC = Prime Hook Creek, MR = Mispillion River, BR = Broadkill River.

In the state of Delaware impounded wetlands comprise ~11% of the total 36,500 ha of tidal wetlands (DNREC, 1994). Prime Hook NWR alone contains 28% (1122 ha) of the impounded wetland area (USFWS, 2013). Since 2009, the Refuge has been impacted by a series of coastal storms that have significantly increased the area of open water while decreasing the extent of tidal wetland. Consequently, tides exceeding mean higher high water (MHHW) have increased in frequency from 10 to 20 events per year in the 1980s to 15–30 in recent years (USFWS, 2013). This trend has raised concerns over impoundment overtopping during coastal storms, chronic flooding of roadways, and the sustainability of the wetland complex as a whole. A fundamental question among state and federal regulatory officials is the accretionary status of refuge marshes and their potential to maintain optimal elevation within the tidal frame.

In this paper, the Prime Hook NWR is presented as an analogue to other managed marsh systems on the US East Coast in that it is composed of both impounded and unrestricted marshes with variable rates of sediment accumulation and accretion. The working hypothesis of this study was that rates of accretion in the impounded Units II and III are lower than in tidal Units I and IV because of the restricted tidal flow and reduced potential for mineral sedimentation. We conducted a study with the following objectives: (1) investigate marsh soil properties for evidence of change related to wetland impoundment activities since the 1980s; (2) establish the accretionary status of Refuge marshlands compared to local rates of RSLR; and (3) determine the relative influences of mineral sediment versus organic matter accumulation on measured rates of accretion for insight on biotic and physical processes of soil formation.

2. Study site

Prime Hook NWR is a tidal wetland complex located on the southwestern shore of the Delaware Bay Estuary (Fig. 1). Prior to